A QGP Classifier based on Convolutional Neural Network for the CBM Experiment

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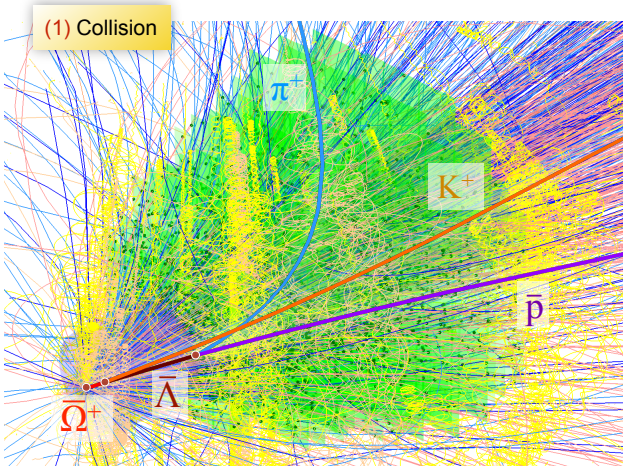
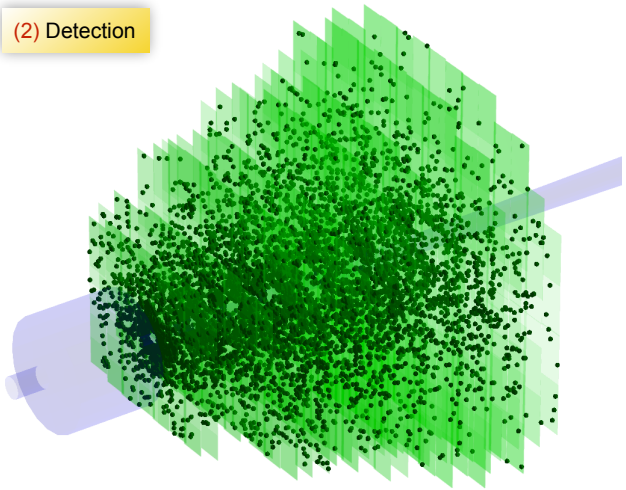
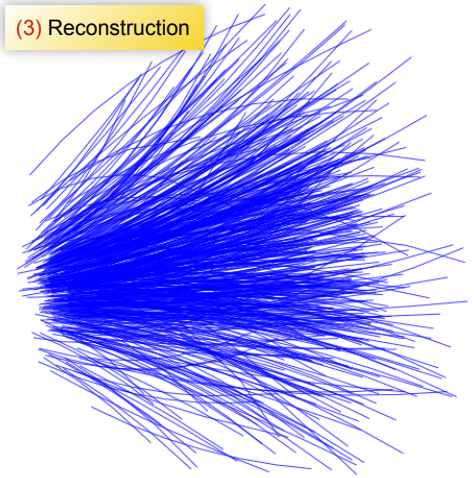
FLES: First Level Event Selection in CBM





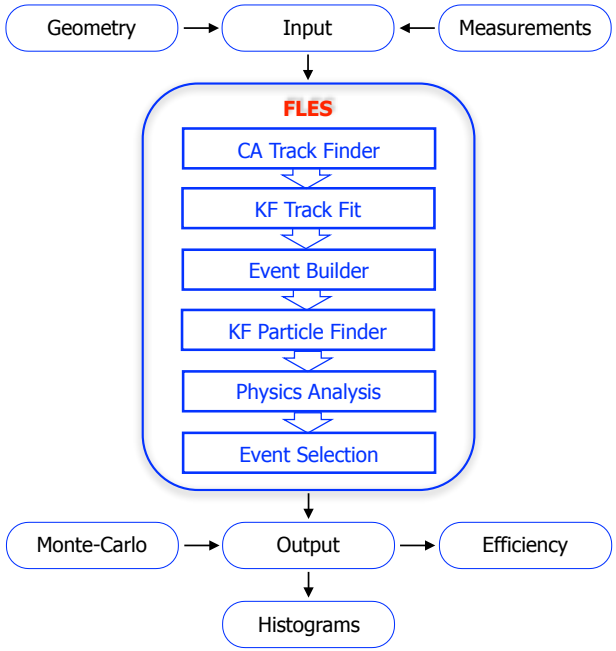


- Future fixed-target heavy-ion experiment at FAIR
- Explore the phase diagram at high net-baryon densities
- 10^7 Au+Au collisions/sec
- ~ 1000 charged particles/collision
- Non-homogeneous magnetic field
- Double-sided strip detectors
- 4D reconstruction of time slices.

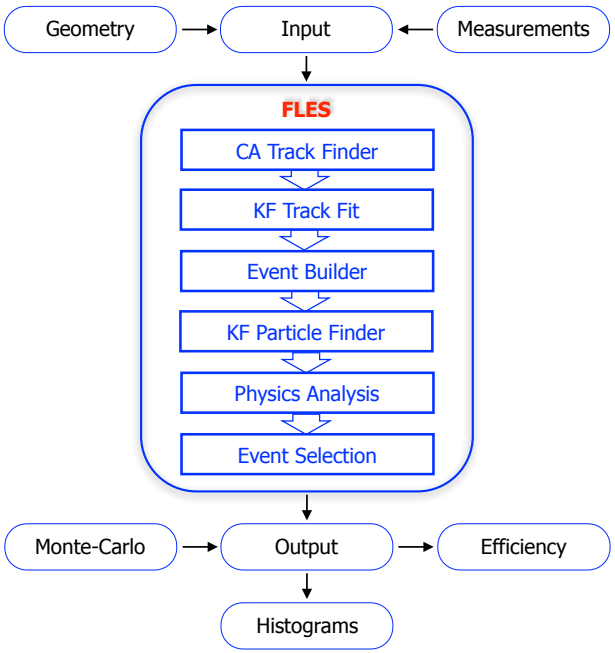
The full event reconstruction will be done on-line at the First-Level Event Selection (FLES) and off-line using the same FLES reconstruction package.

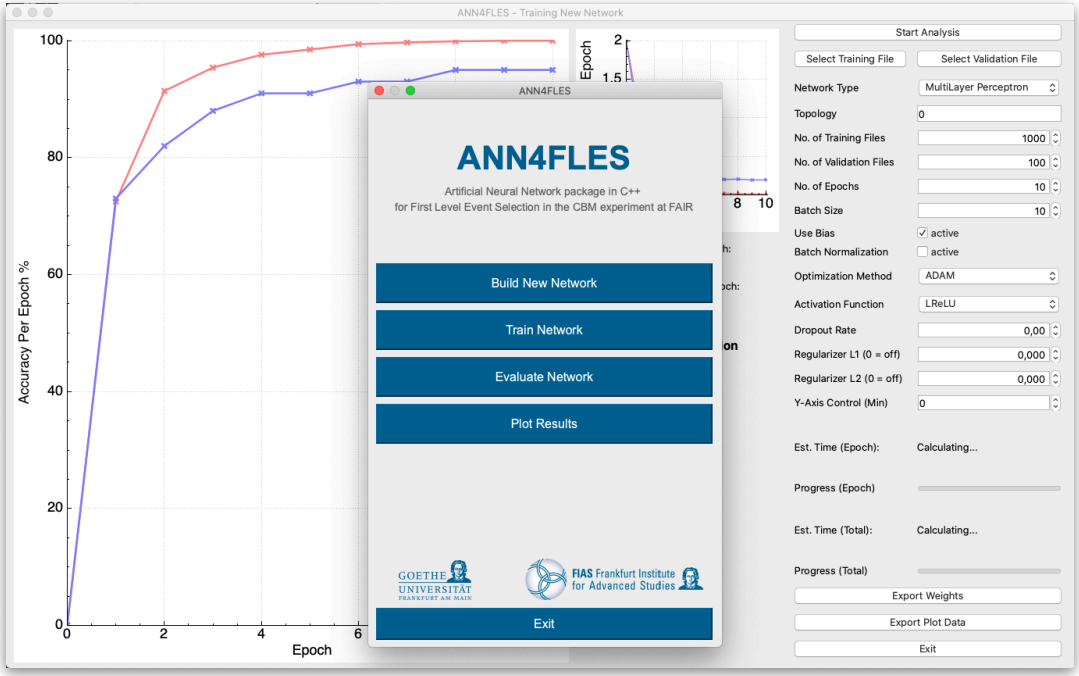
- Cellular Automaton (CA) Track Finder
- Kalman Filter (KF) Track Fitter
- KF short-lived Particle Finder

All reconstruction algorithms are vectorized and parallelized.



ANN4FLES : Artificial Neural Networks for FLES

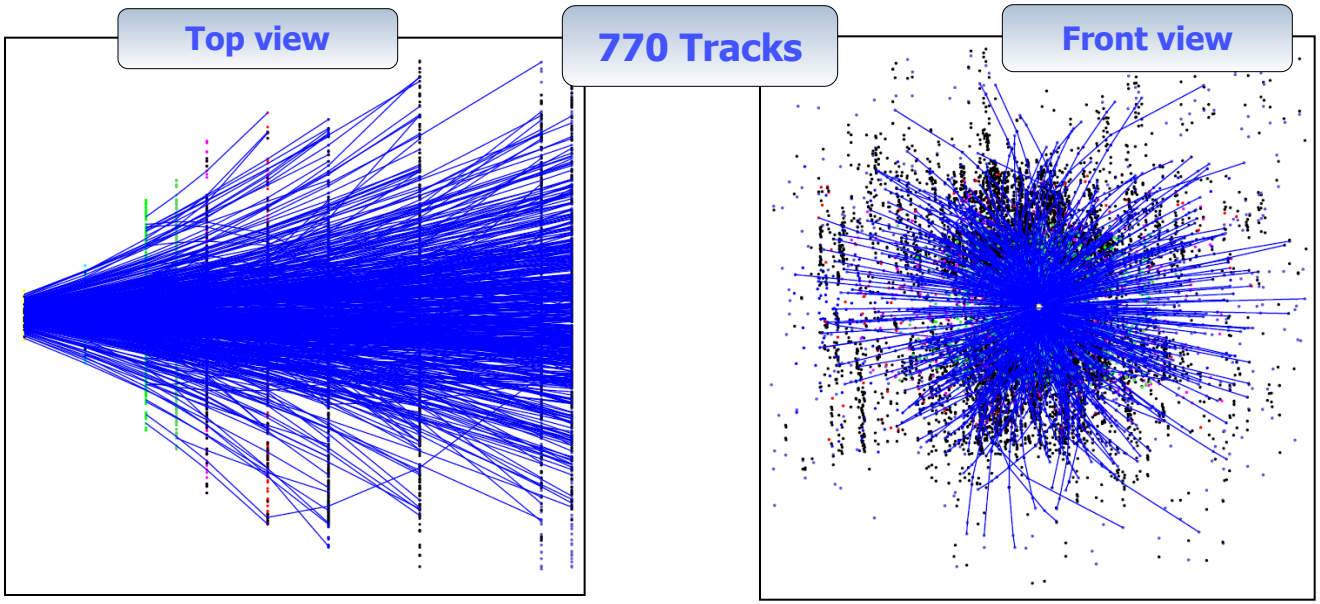


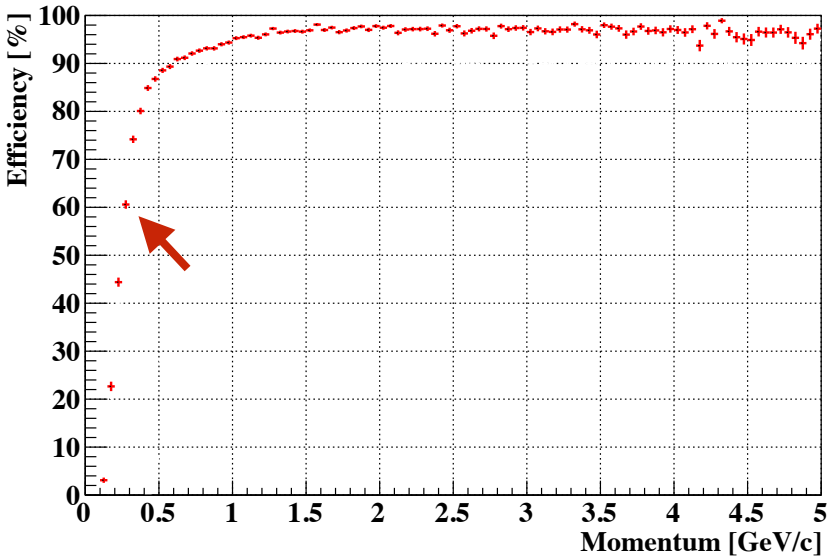


- ANN4FLES is a fast **C++ package** designed for use of Artificial Neural Networks (ANN) in the CBM experiment.
- The package includes a Graphical User Interface (GUI) for network selection and hyperparameter adjustment.
- **Implemented networks** in ANN4FLES include:
  - Multilayer Perceptron (MLP),
  - Convolutional Neural Network (CNN),
  - Recurrent Neural Networks (RNN),
  - Graph Neural Networks (GNN), and
  - Bayesian Neural Network (BNN).
- Extensive **testing** on datasets like **MNIST**, **CIFAR**, **Cora**, etc., has been **performed** and **compared** with PyTorch.

Cellular Automaton (CA) Track Finder

I. Kulakov

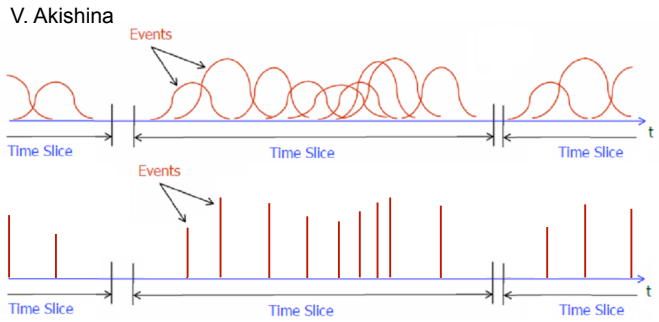




Track category	Eff, %
All tracks	90.9
Primary high-p	97.5
Primary low-p	92.6
Secondary high-p	91.1
Secondary low-p	63.8
Clone level	0.4
Ghost level	5.9
MC tracks found	134
Time, ms/ev	10

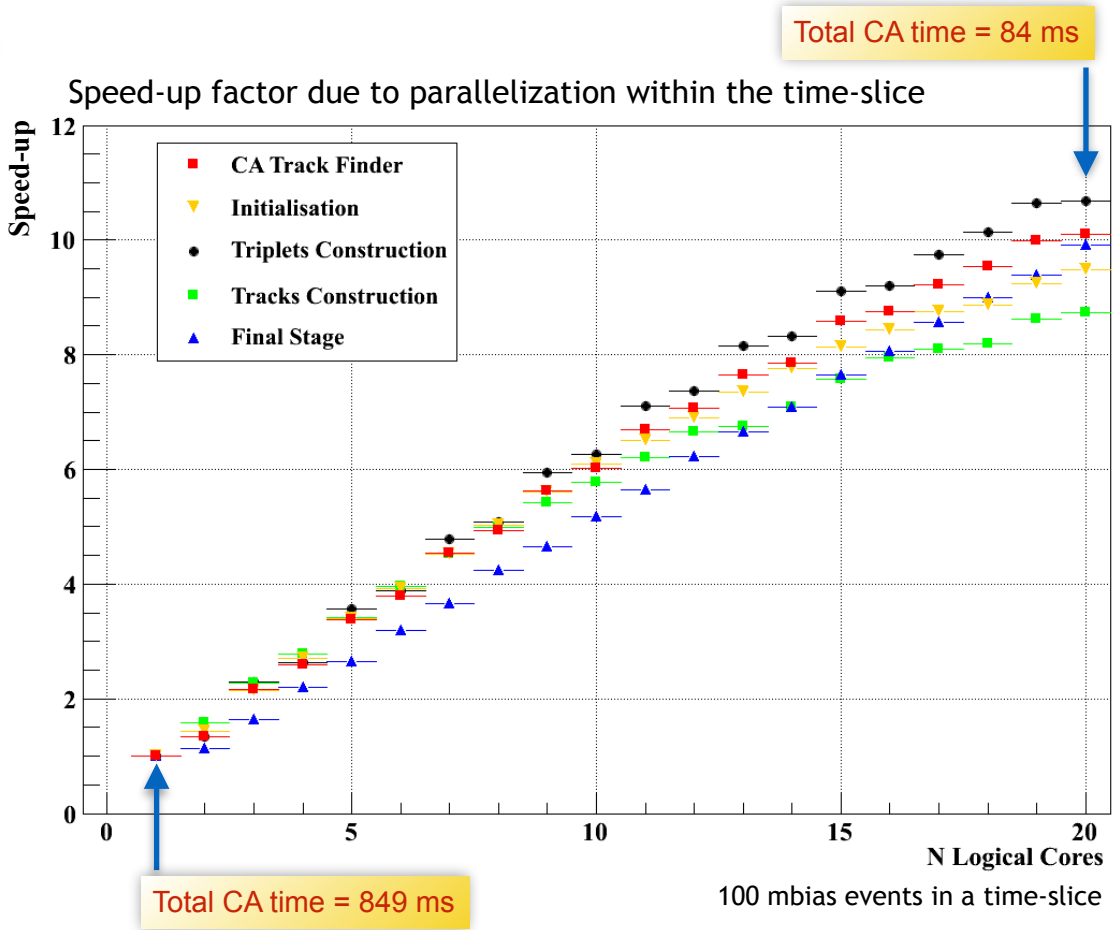
Fast and efficient track finder

Time-based (4D) Track Reconstruction



- The beam in the CBM will have no bunch structure, but continuous.
- Measurements in this case will be 4D (x, y, z, t).
- Significant overlapping of events in the detector system.
- Reconstruction of time slices rather than events is needed.

Efficiency, %	3D	4D
All tracks	83.8	83.0
Primary high-p	96.1	92.8
Primary low-p	79.8	83.1
Secondary high-p	76.6	73.2
Secondary low-p	40.9	36.8
Clone level	0.4	1.7
Ghost level	0.1	0.3
Time/event/core, ms	8.2	8.5

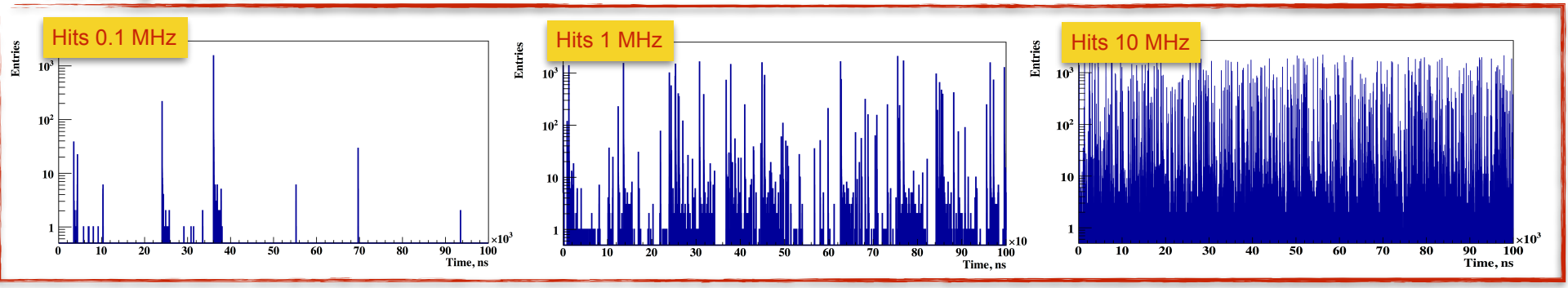


3D reconstruction time 8.2 ms/event is recovered in 4D case

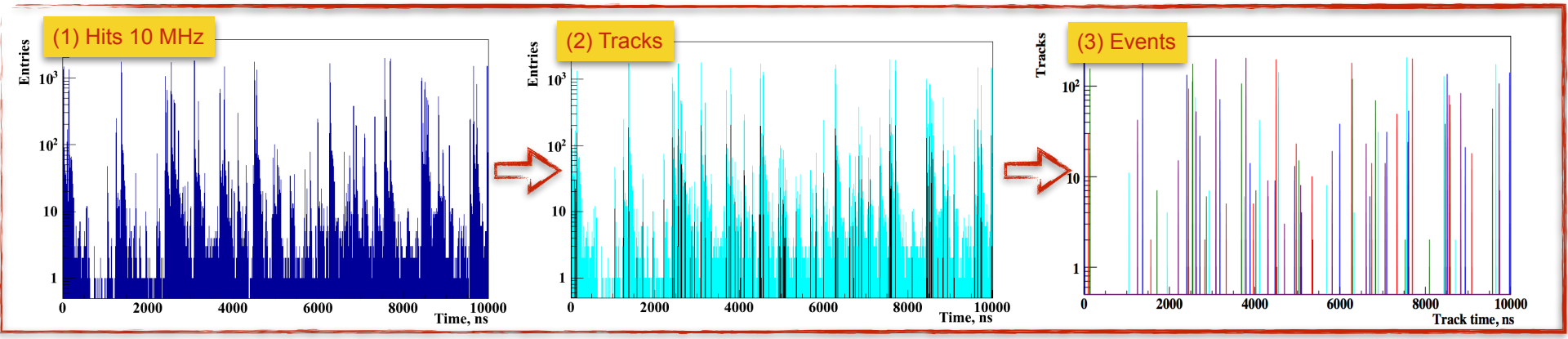
4D Event Building at 10 MHz

V. Akishina

Hits at high input rates



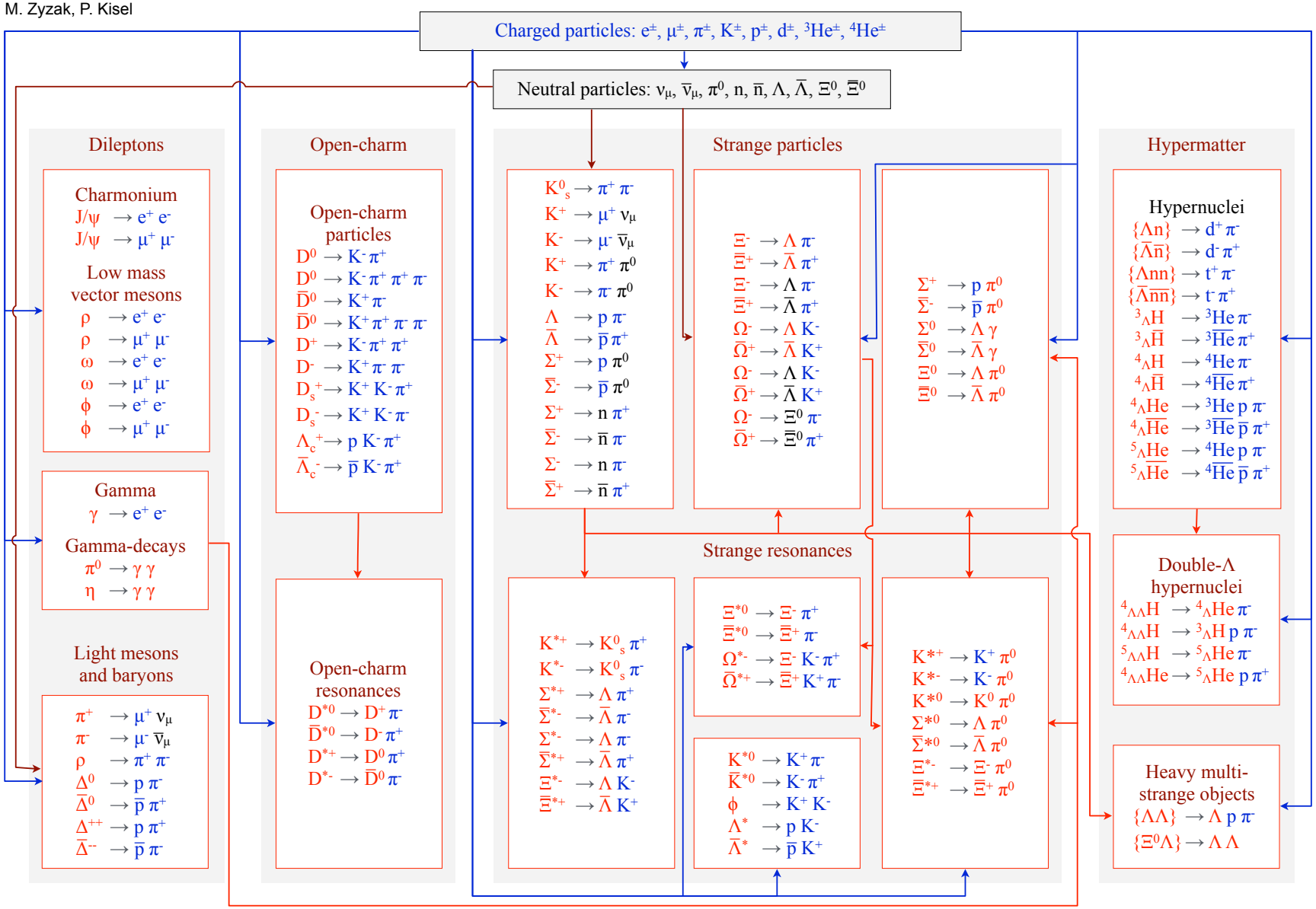
From hits to tracks to events



Reconstructed tracks clearly represent groups, which correspond to the original events

KF Particle Finder for Online Analysis and Selection

M. Zyzak, P. Kisel

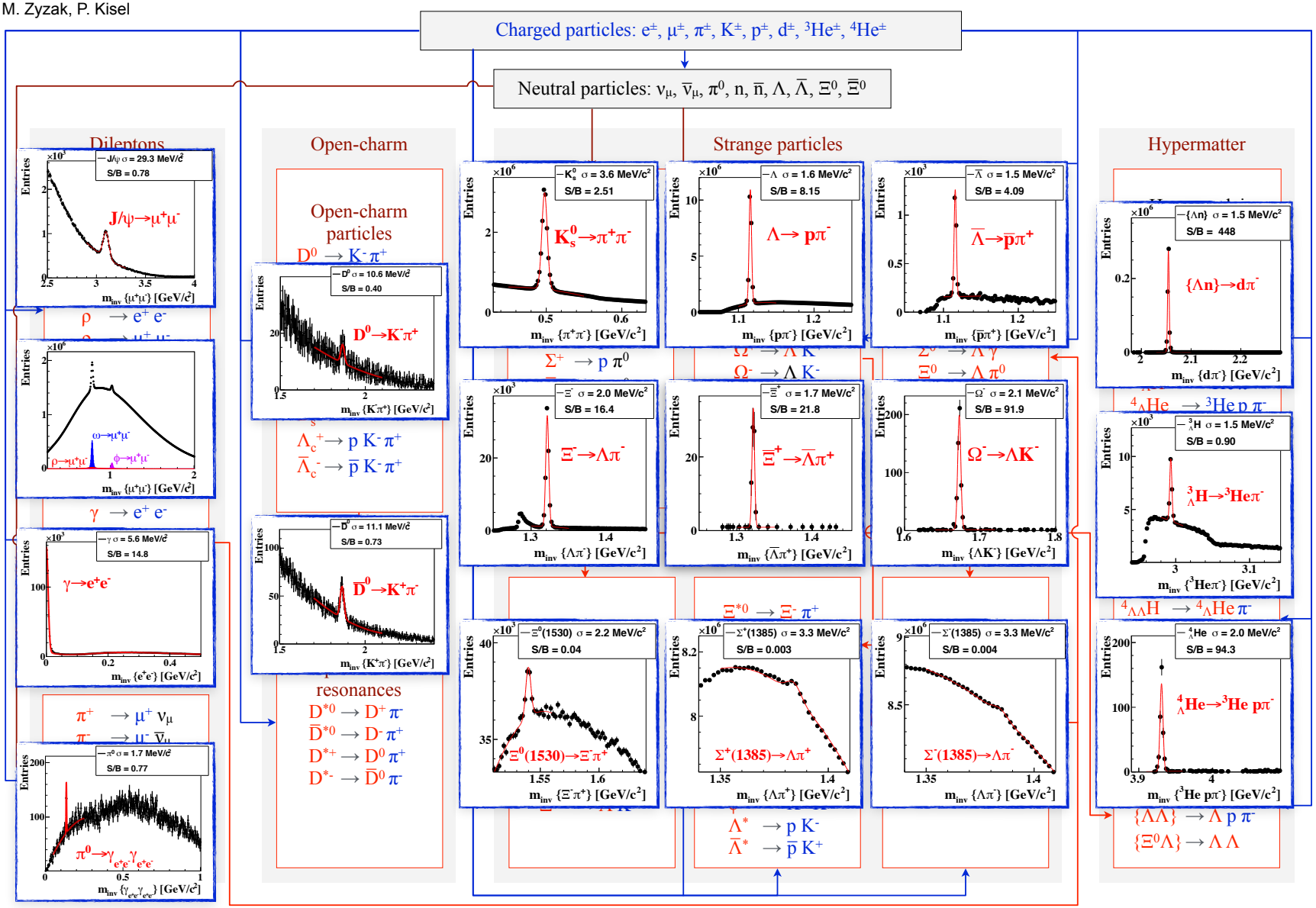


Online search for short-lived particles

(mbias: 1.4 ms; central: 10.5 ms)/event/core

KF Particle Finder for Online Analysis and Selection

M. Zyzak, P. Kisel



ANN based Particle Competition in the KF Particle Finder

M. Zyzak, A. Banerjee, R. Lakos

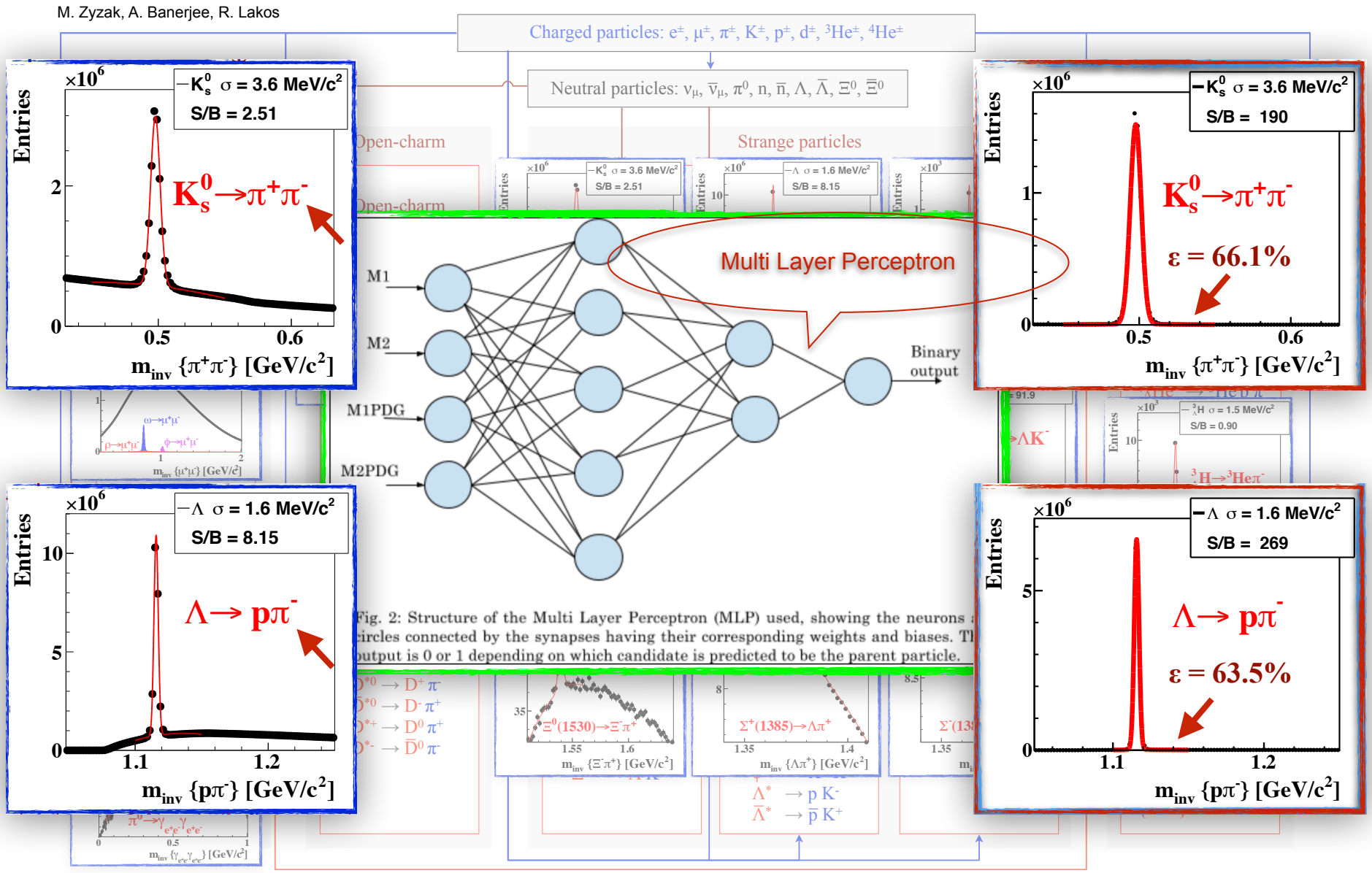
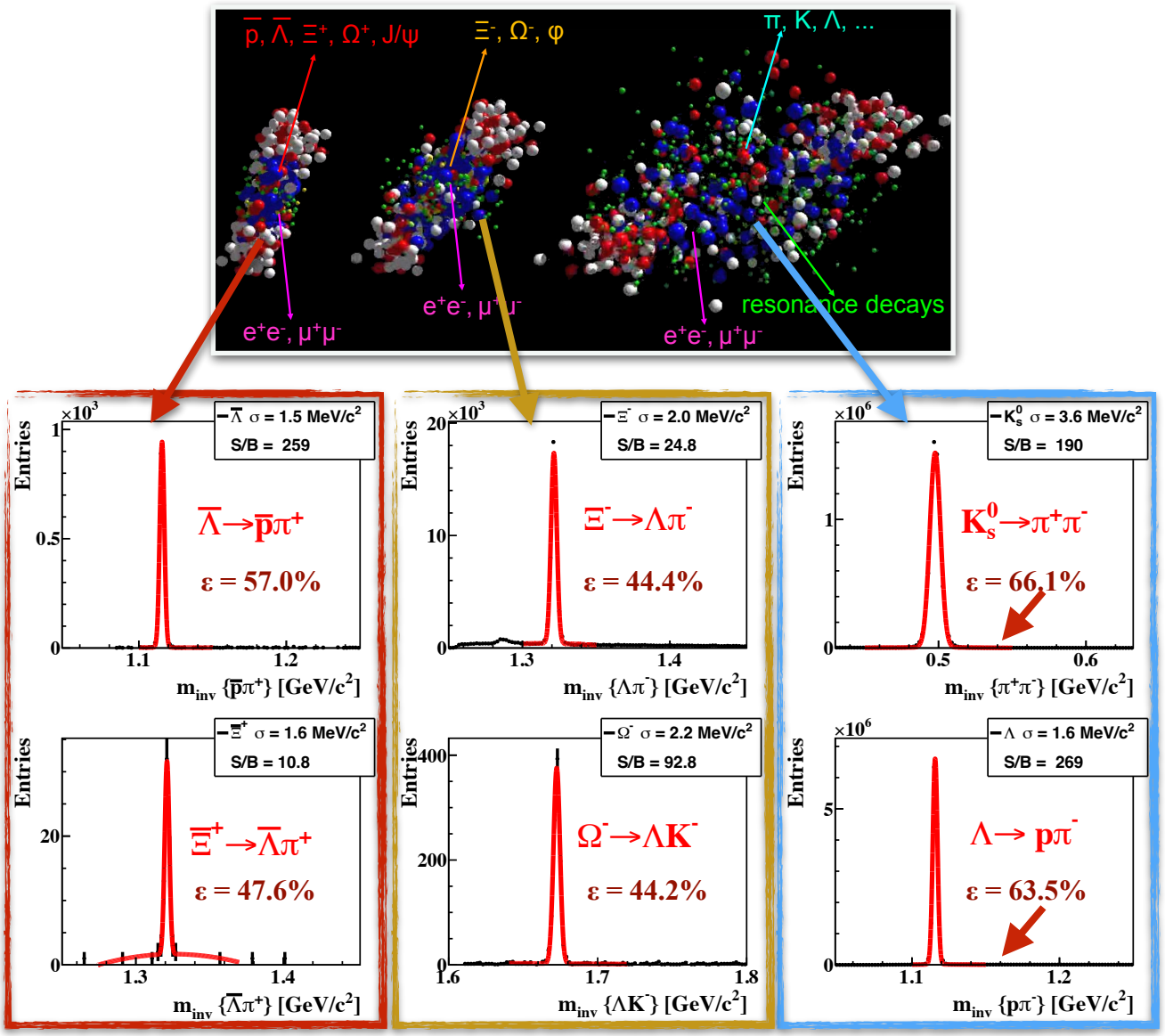


Fig. 2: Structure of the Multi Layer Perceptron (MLP) used, showing the neurons as circles connected by the synapses having their corresponding weights and biases. The output is 0 or 1 depending on which candidate is predicted to be the parent particle.

A Multilayer Perceptron is used to solve the particle competition task in the KF Particle Finder

Clean Probes of Collision Stages

M. Zyzak

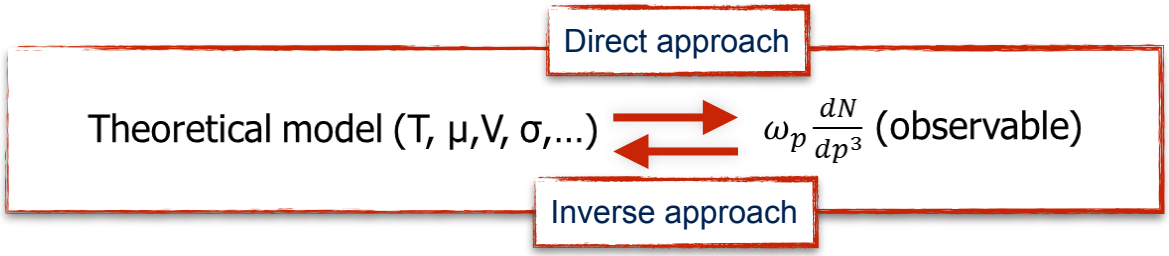


AuAu, 10 AGeV, 3.5M central UrQMD events, MC PID

Study of the properties of colliding matter is possible

CBM: Online Physics Analysis?

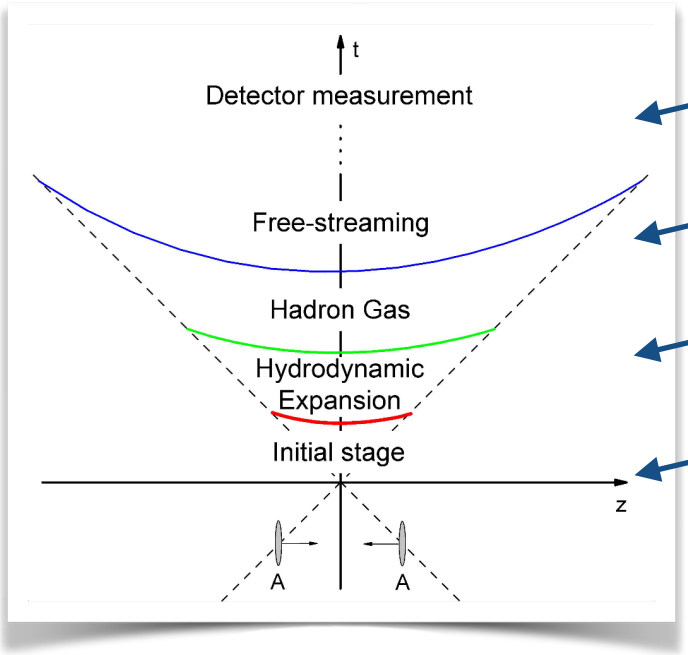
Online physics analysis = online extraction of medium properties in heavy-ion collisions



Motivation:

- determination of physical properties of QCD matter created in HIC (temperature, flow, phase transitions, …),

Stages of collision



Models for different stages

Final momentum spectrum (Blast-Wave, Tsallis, …)

Statistical-thermal models for chemical freeze-out (ideal hadron gas, Van der Waals hadron gas, Hagedorn states, …)

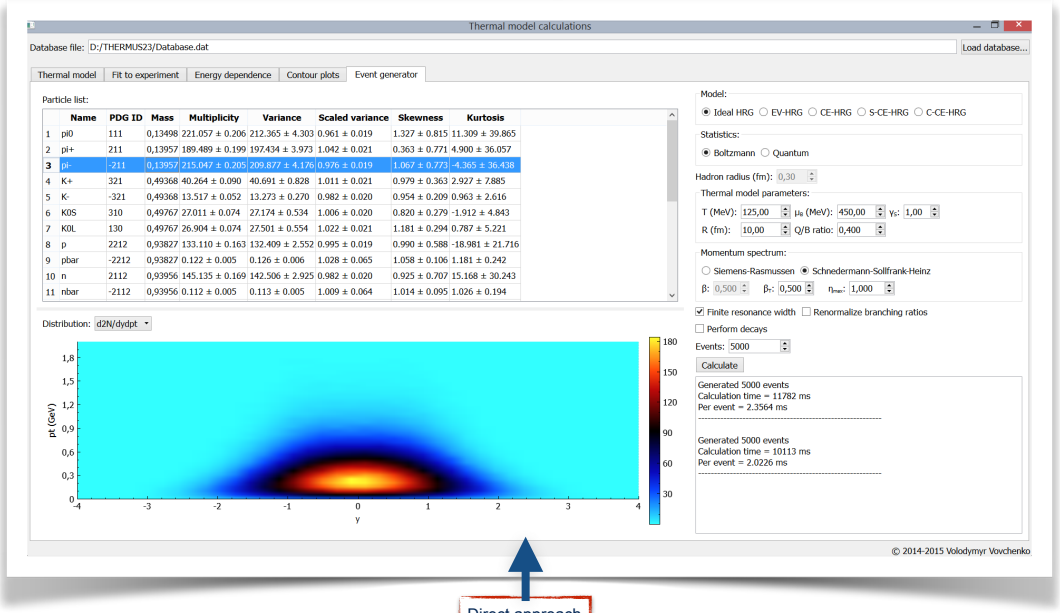
Relativistic hydrodynamics (ideal, viscous; (0+1)D, (1+1)D, (3+1)D, …)

Initial stage (Glauber, CGC, …)

How to extract the parameters of theoretical models?

CBM: Online Physics Analysis (macroscopic)

V. Vovchenko

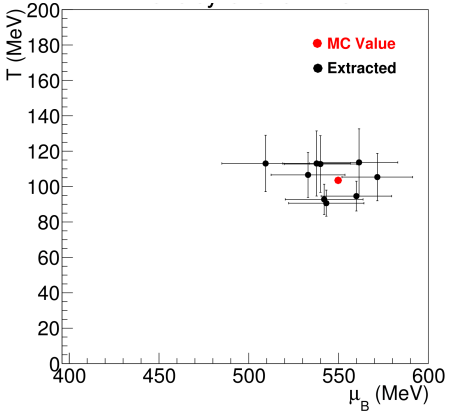


Direct approach

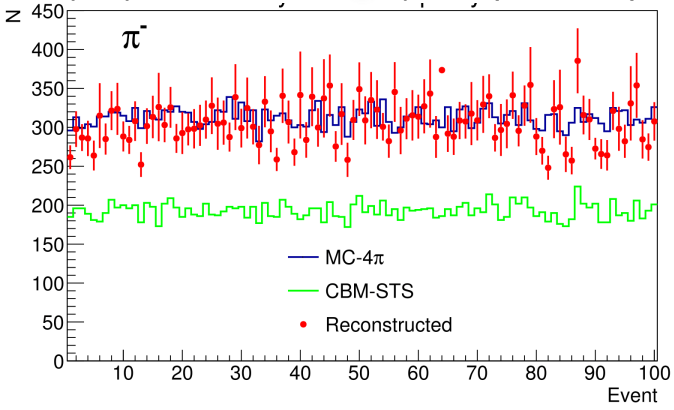
Theoretical model (T, μ,V, σ,...) $\omega_p \frac{dN}{dp^3}$ (observable)

Inverse approach

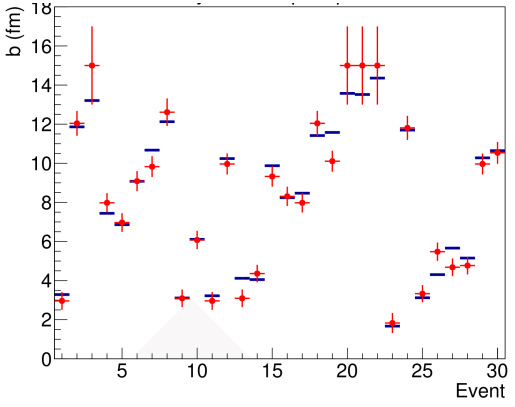
E.-by-E. extraction of T and μ_B (HRG)



E.-by-E. yield estimate incl. acceptance (Blast-Wave)



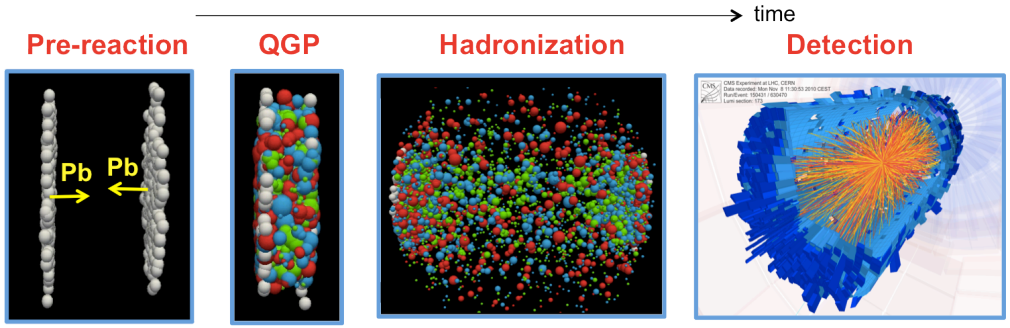
E.-by-E. impact parameter (Glauber)



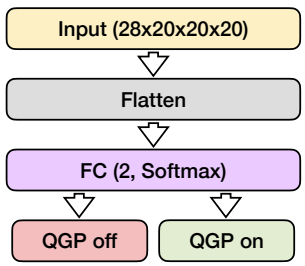
Extraction of the parameters of macroscopic theoretical models is feasible

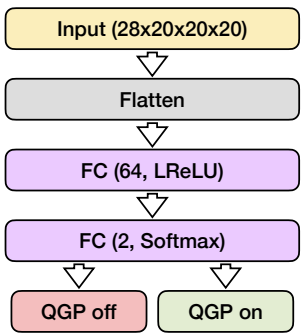
CBM: Online Physics Analysis (microscopic)

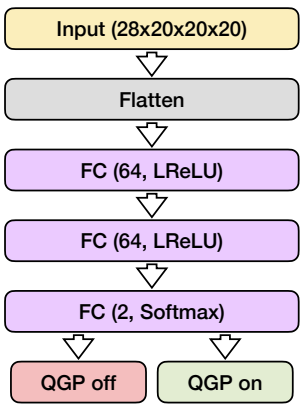
A. Belousov, R. Lakos, A. Mithran, O. Tyagi

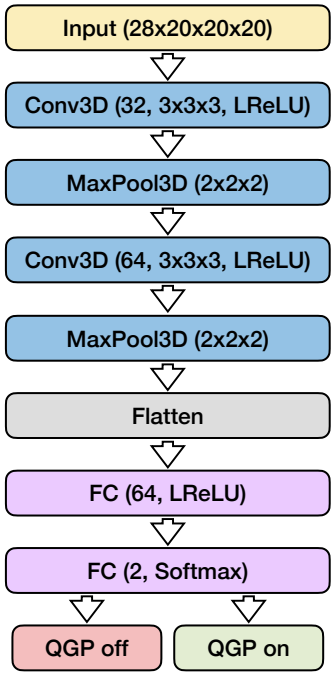


- A **QGP** can be formed by **compressing** a large amount of energy into a small volume.
- **Direct observation** of QGP is **not possible**.
- Rely on the **produced particles** as **probes**.
- **Classify events** based on the **reconstructed particles**.





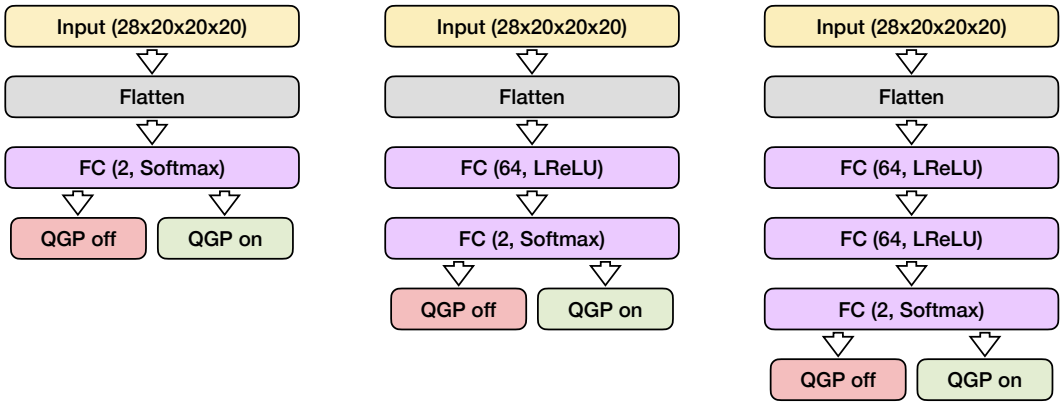




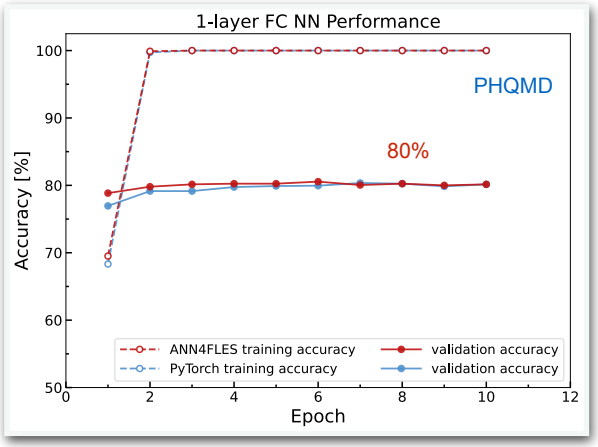
Use of Artificial Neural Networks for selection of events with QGP

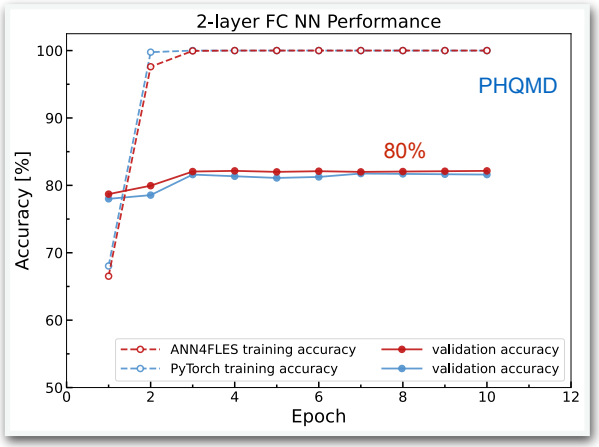
Fully-Connected Neural Networks (FCNN)

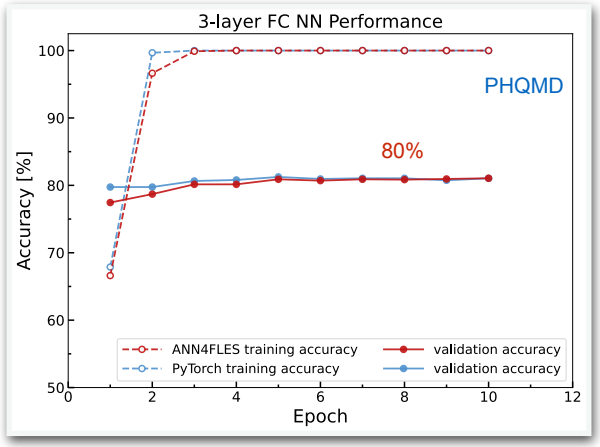
A. Belousov, R. Lakos



Structure of **one-**, **two-** and **three-layer** Fully-Connected Neural Networks used for QGP detection





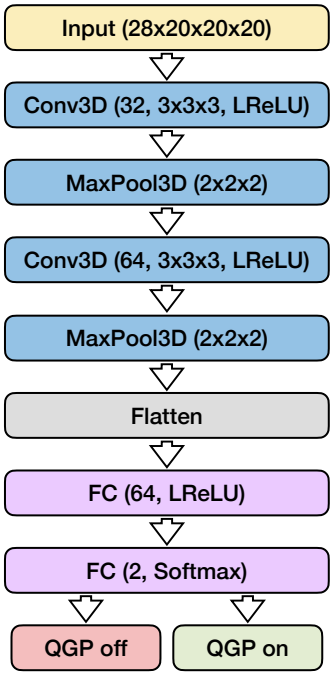


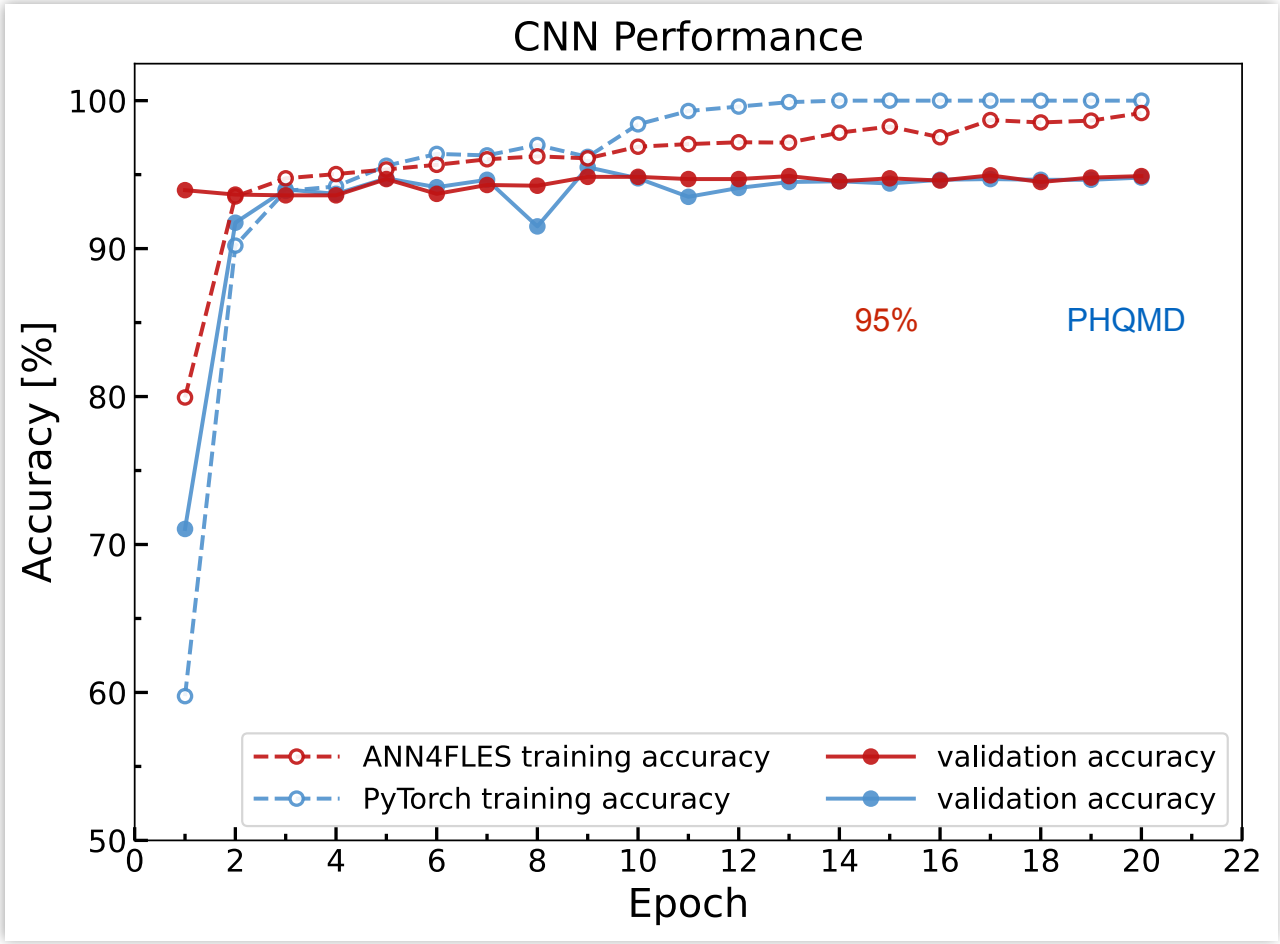
Training and validation accuracy for the **FCNN** networks

A Fully-Connected Neural Network (**FCNN**) based **QGP Trigger** is probably **not feasible**

Convolutional Neural Network (CNN)

A. Belousov, A. Mithran





Training and **validation** accuracy for the **CNN**

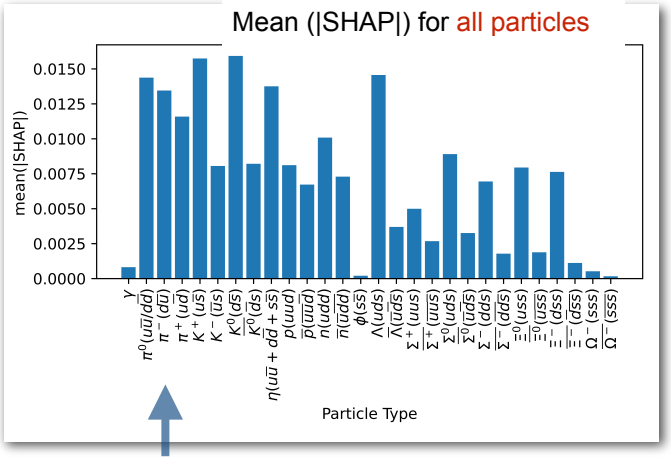
A Convolutional Neural Network (**CNN**) based **QGP Trigger** is probably **feasible**

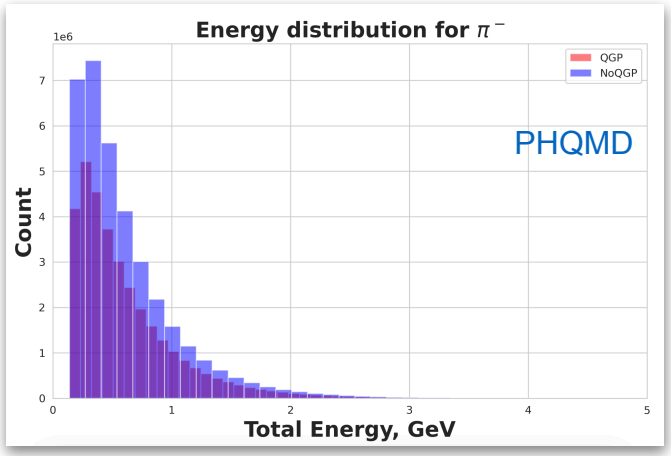
Interpretable ANN: Shapley Additive Explanations

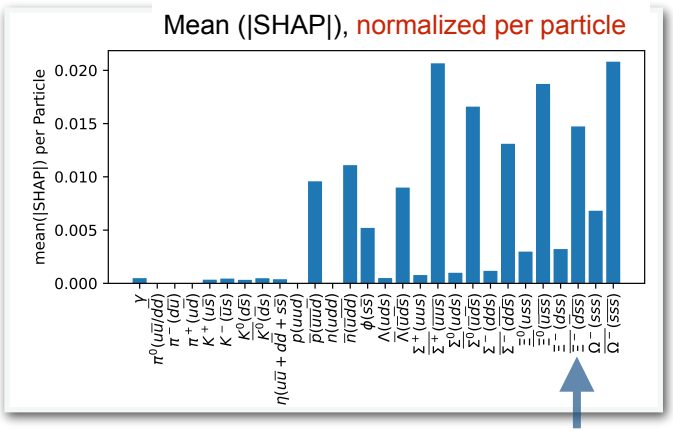
A. Belousov, O. Tyagi

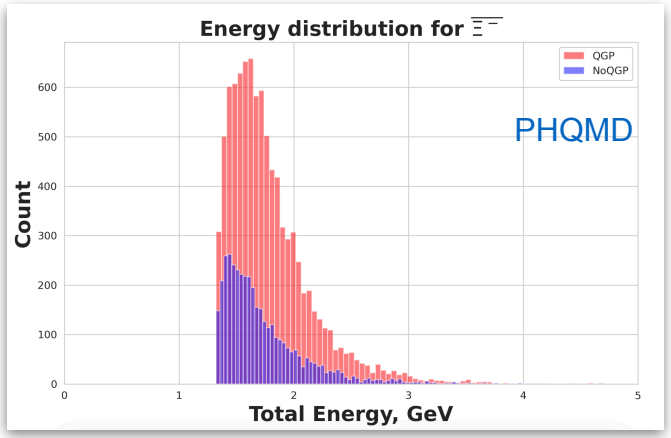
Method based on cooperative game theory used to increase transparency and interpretability of machine learning models.

For each feature, SHAP score is determined by evaluating the average contribution of adding the feature over all possible feature subsets defined without that feature.







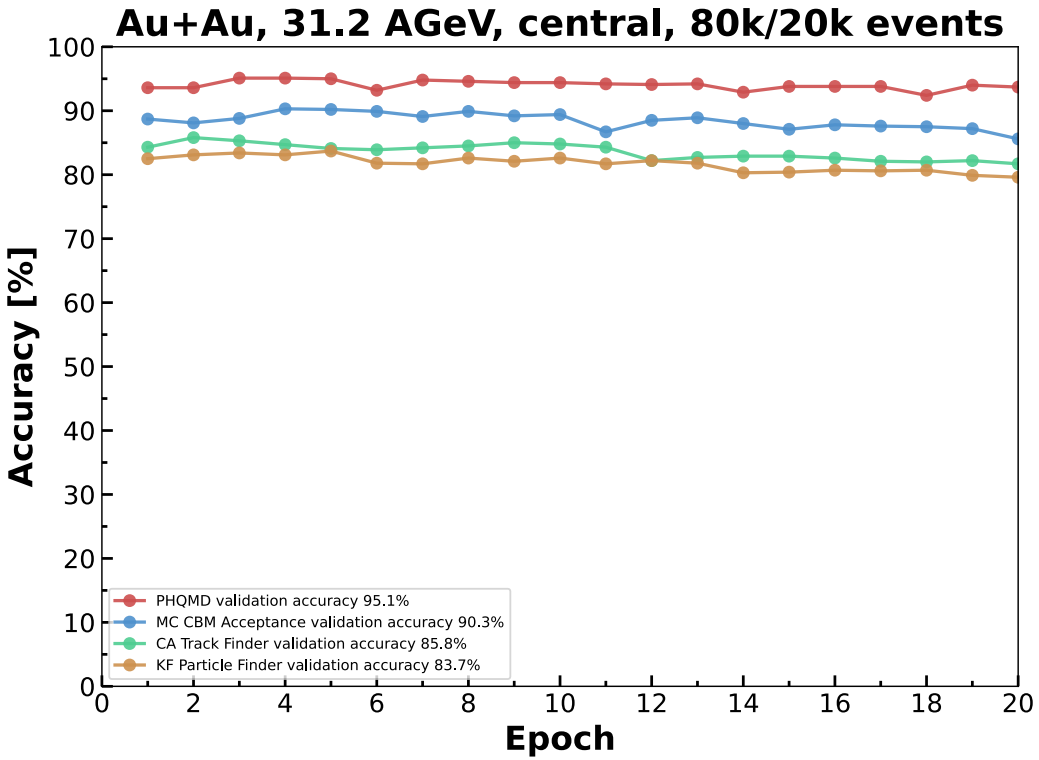


- Light particles are important for model prediction
- Anti-baryons are more important than baryons per particle

SHAP analysis reveals that ANN has learned the correct characteristics associated with QGP production

CBM: ANN based QGP Classification

A. Belousov, P. Kisel



	Stage	Efficiency	Drop
1	CNN on PHQMD	**95.1%**	
2	CBM Acceptance	**90.3%**	**- 4.8%**
3	CA Track Finder	**85.8%**	**- 4.5%**
4	KF Particle Finder	**83.7%**	**- 2.1%**

Future plans:

1. Improve the efficiency of reconstruction of **anti-baryons** in the **KF Particle Finder**.
2. Improve the efficiency of reconstruction of **low-momentum particles** in the **CA Track Finder**.
3. Use **Large Language Models** (**LLMs**) to account **correlations between particles** produced in the QGP volume.
4. Test on **different theoretical models** (**PHQMD**, **UrQMD**, …?)
5. Test on **real data** (**STAR**, …?).

Online selection of collisions with QGP is possible